

International Performance Measurement and Verification Protocol (IPMVP): Measurement and Verification for Renewable Energy Technologies

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Chapter : Measurement and Verification for Renewable Energy Technologies

1 Introduction

1.1 Overview

A protocol for measuring performance is required if renewable energy technologies are to realize their potential. These technologies make use of sustainable energy sources that are regenerated in nature, and they include solar, wind, biomass (e.g., sustainably harvested food crops, organic wastes, and landfill gas), geothermal, small hydroelectric, ocean thermal, wave, and tidal energy. Renewable energy projects have been, and continue to be, installed all over the world in numerous projects funded by governments, private companies, organizations, and third-party financiers.

Whether a renewable energy system is integrated into a larger energy delivery system or is a stand-alone system, a method of measuring and verifying performance is needed. Project financing, emissions credits, and emissions trading will all benefit from a standardized, widely accepted measurement and verification (M&V) approach that serves the needs of all renewable energy project partners. This chapter describes the characteristics of renewable energy projects, lists barriers to greater use of renewable energy systems, presents M&V options for renewable energy systems within the IPMVP framework, and includes examples and recommendations for specific applications.

1.1.1 Common Benefits

Renewable energy technologies are highly diverse in terms of resources and conversion technologies. Nevertheless, several things are common to all the technologies that distinguish them from energy efficiency projects. Foremost among these is that all renewable energy technologies supply energy rather than reduce the energy consumed. Measuring this energy supply can often serve as a simplified approach to measuring system performance. The productivity of a renewable energy system that is not connected to a utility is directly linked to the amount of energy consumed. An M&V strategy must be able to differentiate between an increase in renewable energy supply and a reduction in the load.

In addition, the performance of a renewable energy system is very much a function of environmental conditions, such as solar radiation or wind speed. These conditions are outside the control of project developers and should be taken into account in any M&V approach.

While capital intensive, renewables may be the least-cost power source in remote areas not served by electric or gas utilities. The cost of installing electric or gas service can easily exceed the initial cost of a renewable energy system to meet a small, remote load such as a well for livestock or a vacation home. Even in urban areas, it can be less expensive to install a small solar power system for a small load such as a cellular phone repeater than it is to connect to utility power.

Renewable energy projects reduce the use of fossil fuels, which lowers the customer's costs for these fuels. Fuel availability and fuel price stability are not issues with renewable energy resources such as sun and wind, so these reduce the risk of investing in an energy project. In addition, employing local trades to

install and operate renewable energy systems is a good way to keep money and jobs in the local community rather than send money outside to pay for imported fuels.

Most renewables generate power with no atmospheric emissions, offsetting the release of pollution associated with fossil fuels. Although economic benefits generally depend on the amount and cost of energy delivered to a site, environmental benefits often involve consideration of the method in which that energy was generated and delivered. This site-versus-source difference is especially noteworthy in the case of electricity, which can be generated at hydroelectric, nuclear, gas, or coal power plants, each with its own environmental impacts and economic value.

Diversifying the energy supply and distributing renewable energy generation around the power transmission system are also sometimes listed as benefits. They could increase or decrease the grid's stability and availability, depending on their impacts on the entire utility grid. Special M&V techniques may be required to quantify these benefits for project participants to include them in the scope of an M&V program.

Many renewable resources, such as the sun and the wind, are intermittent; with technologies based on these resources, a backup source of energy is usually required. When a renewable energy system is installed with an existing fossil fuel system as backup, the increased capacity and redundancy that can be measured in a carefully structured M&V approach adds value. However, the claim of greater reliability would have to be included in project performance estimates, and the M&V program would have to include a measurement of system reliability.

1.1.2 Existing Barriers

Several barriers currently impede widespread increases in the use of renewable energy. Renewable energy systems often involve a lot of equipment to harvest the diffuse solar or wind resource, and consequently require a lot of capital to implement. This high initial cost means that special consideration must be given to the ways in which the properties and benefits of these systems impact implementation, cost, and financing.

It is difficult to compare renewable energy systems with fossil-fuel systems in terms of cost, performance, emissions, land use impacts, and other criteria because they operate very differently. In addition, because of the frequent need for a backup system, the cost of a renewable energy system rarely displaces the cost of a conventional energy system entirely.

The scarcity of information concerning the potential and proper application of renewable energy is another barrier to broad implementation. A major benefit of renewable systems, for example, is their low operating cost, which is usually the result of low (or no) fuel costs. However, even this simple fact is not widely known. In addition, many of the benefits of renewable energy systems are external to conventional evaluation and accounting techniques. Therefore, for these and other reasons, a sound protocol is needed for measuring performance and quantifying benefits unique to renewable energy systems—one that can be used to measure and clearly communicate the benefits of renewable energy.

1.2 Purpose and Scope

Supplies of renewable energy complement the reductions in load achieved through energy efficiency measures. However, an M&V strategy for renewable energy must be able to differentiate between a reduction in fossil fuel use caused by renewable energy delivery as opposed to one caused by a reduction in the load (by efficiency measures or curtailment).

Renewable energy projects are often capital-intensive, requiring a longer investment term than that of energy efficiency projects. Therefore, an M&V program for renewable energy must verify that benefits are sustained over a long period of time. This situation favors M&V approaches that may cost more initially but have lower annual operating costs.

Because renewable energy systems often rely on intermittent resources, special procedures are required to measure their effects on an integrated energy system. A sophisticated M&V program may be needed to credit the generation capacity of a renewable energy system that is part of an integrated system. Moreover, the capacity to deliver power on demand—dispatchable power—may be as valuable as the amount of energy supplied over time.

1.2.1 Rationale

An established M&V protocol offers a systematic foundation for providing greater confidence that the predicted economic and environmental benefits of investments in renewable energy projects will be realized. This is extremely important to project developers and energy service companies (ESCOs), who bear the financial risk of project nonperformance. Implementation of a thorough M&V procedure based on the approaches described in this chapter can increase investors' confidence in the reliability of estimates of energy generated and other benefits. M&V can also provide diagnostic information that can be used to improve the performance of a system.

In addition, regulatory bodies require a standard method for measuring progress and compliance with energy and emissions requirements in order to implement their programs widely. The increase in reliability provided by M&V allows national and international bodies to be confident that the emissions offset allocation resulting from investments in renewable energy can be calculated with great precision in a globally consistent manner.

1.2.2 Objectives

From the earliest stages of project development through operation of a completed renewable energy system, M&V may actually have several objectives:

- To measure existing daily, weekly, and annual demand and/or consumption load profiles to establish the energy use baseline and to ascertain the size of the system, energy storage requirements, and other design characteristics of a project. These load profiles also provide information needed to establish project feasibility.
- To serve as a commissioning tool in order to confirm that systems were installed and are operating as intended.
- To serve as the basis for payments to a project developer or ESCO over the term of a performance contract. Payments can be directly tied to measured performance. Alternatively, or perhaps in addition, M&V results could be used to verify a minimum level of performance guaranteed in the contract.
- To provide data that can be used as diagnostics, which continually help to sustain system performance and benefits over time.

- To increase customers' confidence and reduce transaction costs by using a defined, accepted, and proven M&V approach to facilitate negotiations during financing and contract development.

– For project developers, financing entities, and large customers (such as governments), there are additional M&V objectives extending beyond the scope of an individual contract. M&V programs can be designed to validate or improve computer simulations or other predictions of system performance, thus reducing project risk and increasing investors' confidence in predictions of project benefits.

– M&V results of existing projects provide developers, investors, lenders, and customers with more confidence regarding the value of future projects than engineering estimates do.

– An M&V protocol familiar to both parties reduces transaction costs by facilitating negotiations.

– A protocol would provide a means to pool projects for financing based on their M&V characteristics.

– By helping investors to understand and mitigate risk, a well-established protocol for measuring the benefits of a project may help obtain less costly project financing.

- To secure the full financial benefits of emissions reductions, such as emissions trading. To verify compliance with emissions reduction targets, regulating bodies will need to adopt a protocol for measuring emissions reductions. A protocol common to all projects is required to claim and trade emissions credits.
- To help certify a "green power" program. Although the certification of green power programs, which offer power generated from renewable energy systems to utility customers, is beyond the scope of the IPMVP, the protocols presented here could be used in such a certification process.

**EXAMPLE:
GUARANTEED SOLAR RESULTS**

The concept of *Garantie de Resultats Solarieres* (GRS), or Guaranteed Solar Results, has been applied to the implementation of several large water-heating systems. A particular level of energy delivery is guaranteed to the client by a "technical pool" of technical and financial resources that will compensate the client if measured delivery falls short of the guarantee. Energy delivery, key temperatures, and pump status are monitored and reported remotely through telephone lines. The table below lists the guaranteed and measured performance for three GRS projects (Roditi 1999).

Annual results of selected GRS projects, 1995
[in kilowatt-hours (kWh)]

	Guarantee	Measured
Castres Hospital, Southern France	50,000	54,580
Hipocampo Playa Hotel, Mallorca	106,039	159,693
Heliomarin Centre, Vallauris	133,719	152,119

2 Baseline Definition and Development

2.1 General Issues

Some general issues unique to renewable energy are involved in the establishment of a baseline of energy use and costs for M&V purposes. These include the fact that renewable energy systems deliver energy rather than simply reduce consumption, as noted, and that renewable energy systems are often located in remote areas not served by utilities.

Because renewable energy technologies are used in an energy delivery system, there is no need for a baseline if performance claims are based on delivery rather than savings. However, the M&V options described here can be applied to measure either the energy delivered by a renewable energy system or the resulting utility energy savings for a facility as a whole. It is important to state that these two may not be exactly the same and to specify whether performance claims are based on delivery or on savings.

Metering of delivered energy without a baseline is often the recommended M&V approach for renewable energy systems because it is very accurate, moderate in cost, and measures elements of project performance over which the developer has some control. For example, a solar water heating system may deliver a certain amount of heat, but utility energy savings for the facility would be the amount delivered by the solar system divided by the efficiency of the water heater. In this case, the developer of the solar project would not have control over the efficiency of the existing water heater, so it is more appropriate to base performance claims on energy delivery rather than on savings.

Renewable energy systems are often cost effective as the only source of power in remote locations where utility power is unavailable. A baseline based on the utility or another type of on-site generation could be arbitrary and rather meaningless in such situations. Nevertheless, a baseline could be needed to estimate utility cost savings or to calculate savings as a result of another selected M&V option. The baseline could then be defined as the energy use or cost that would be incurred without the renewable energy system.

2.2 Baseline Applications

Energy savings are estimated indirectly by calculating the difference between the baseline energy or demand and the metered energy or demand after a renewable energy system is installed. Metering may be done with a kilowatt-hour (kWh) meter, a gas meter, or a run-time meter on a gas or electric appliance. It is important to account for the efficiency of the fossil fuel or electric appliance if only the end use (e.g., the amount of hot water used) is measured.

Selecting a method of determining the baseline depends on several factors, including the characteristics and needs of the project, the data available, and whether there is a load before the renewable energy system is to be installed. When only the utility energy is measured and renewable energy delivery is not measured directly, there are four ways to calculate savings relative to a baseline: comparison with a control group, before-and-after comparison, on-and-off comparison, and the calculated reference method (Christensen and Burch 1993).

2.2.1 Comparison with Control Group

Compare metered energy use with similar loads (i.e., the control group) that do not have renewable energy systems. The average energy use and cost of the control group establish the baseline. (Note: A control group can be used only if a statistically significant number of identical units do not use renewable energy systems.)

2.2.2 Before-and-After Comparison

Measure energy use before the renewable energy system is installed and compare it with usage occurring after the system is installed, adjusting for any changes in operating conditions or in the use of the facility that have occurred between the two measurements. The energy use and cost before the renewable energy system is installed establish the baseline. (Note: The before-and-after method can be used only in a retrofit application in which data have been collected before the renewable energy system was installed and began operating.)

2.2.3 On-and Off-Comparison

Measure energy use while the renewable energy system is on. Then, turn the renewable energy system off by bypassing it. Next, compare energy usage when the system was off with usage when the system was on. The resulting energy use and cost when the renewable energy system is turned off and properly bypassed establish the baseline. (Note: The on-and-off technique can be used only if there is an auxiliary energy system in addition to the renewable energy system, and the auxiliary system can be used in defining the baseline.)

2.2.4 Calculated Reference Method

Determine baseline energy use by using engineering calculations calibrated to actual energy use patterns, and subtract metered energy usage to estimate renewable energy delivery. These engineering calculations often assume that the system adheres to applicable codes and standards in selecting hypothetical values for parameters such as equipment efficiency. (Note: A calculated reference is needed in new construction involving renewable energy, because there are no load data to use in establishing a baseline.)

3 M&V Planning and Processes

To integrate M&V, project participants begin with a protocol, formulate a plan, and then implement that plan in a specific M&V program for the project.

The *protocol* for M&V for renewable energy projects is the IPMVP. It does so by defining terms, identifying options, and recommending procedures.

To *formulate a plan*, the first step is to identify the goals and objectives of the M&V program, as well as the strategies and techniques—the M&V options—needed to achieve those goals and objectives. Goals often focus on measuring the benefits of a project. They can also involve isolating from one another the effects of various measures and technologies planned for the project. Often, energy efficiency measures and renewable energy projects are implemented together, and one goal of an M&V plan may be to discern the savings attributable to each. In other words, the benefits of a renewable energy system may have to be isolated from the benefits of energy efficiency measures implemented in the same building in order to measure the benefit from each of them.

Implementation can proceed after appropriate M&V options are selected for inclusion in the plan and a renewable energy system is installed and operating. Appropriate M&V options can be selected as part of a customized approach to meeting the project's goals. The best M&V options for a project depend on the specific conditions of the project, including the method of financing and the technologies chosen.

3.1 Performance Claims

EXAMPLE: PERFORMANCE CLAIMS

As an example of the many diverse performance claims possible with a renewable energy project, consider a solar ventilation preheating system for a post office in Denver, Colorado. The system is designed to transfer the heat of solar radiation on the building's south wall into preheated ventilation air by means of an 817-square-meter (m^2) unglazed, perforated absorber plate. The supplier claims that the system will perform as follows:

- Deliver 2,800 megajoules (MJ) of solar heat per year
- Save 50 MJ/year in the form of heat recovery from the south wall—the heat, otherwise lost through the south wall, is entrained in the supply air because the absorber plate covers the south wall
- Save 170 MJ of heat in the form of heat recovery from the ceiling
- Reduce the interior ceiling temperature from 30°C to 23°C through destratifying the solar-heated air being introduced high in the building, thus decreasing the use of exhaust fans and saving an additional 2,600 MJ of heat
- Improve occupants' comfort by pressurizing the building and reducing incoming drafts.

Although it is tempting to measure only the first claim listed here—direct energy delivery from the system—an M&V plan to verify each claim of economic, environmental, and comfort benefits is often essential to justify an investment in a project. The cumulative benefit of all the claims exceeds the savings resulting from solar delivery alone, which illustrates the effect of performance claims on project feasibility.

An M&V program is essentially an agreement between a supplier and a consumer. And performance is essentially what the consumer is buying. Therefore, in performance contracting, measuring performance is of primary importance.

An M&V program designed to measure performance must start by clearly articulating the performance of the system that the supplier is claiming to deliver to the consumer. In other words, it must specify the “performance claims.”

The M&V plan clearly states the performance claims, and the M&V program measures performance relative to those claims. The performance claims state what the project is trying to accomplish as well as the basis for savings. The M&V plan articulates the criteria for determining that the performance claims are being achieved and the ways in which the M&V program will confirm performance, in other words, the M&V methods or options.

The performance claims for renewable energy depend on the particular energy conversion technology, application, and business arrangement between the supplier and the consumer. An M&V program should be designed to measure and verify the specific performance claims of the project. To borrow a concept from the International Standards Organization, “*First* state clearly what it is that you do, *then* state how you measure your success at it.”

3.2 Overview of M&V Options

The options for measuring and verifying the energy savings and other benefits resulting from a renewable energy project may be classified into four general categories: Option A: Partially Measured Retrofit Isolation, Option B: Retrofit Isolation, Option C: Whole-Building Analysis, and Option D: Calibrated Simulation Models. The options are not necessarily listed in increasing order of complexity or cost. For example, inspection can be more or less costly than metering, depending on the application. Option B deserves special consideration when evaluating M&V options for a renewable energy system because the energy delivery of most renewable energy systems can be measured directly, without using a baseline or energy savings, as required for energy efficiency measures.

Option A calculates savings by combining field measurements with engineering estimates based on system specifications and inspections to ensure that equipment has been installed according to those specifications and continues to operate properly. This option measures the ability of the system to deliver energy, capacity, and other claimed benefits and applies the measured result to an assumed set of operating conditions. Option A does not, however, involve continuously measuring performance. Simply stipulating savings with no actual measurement is not considered an M&V approach in the IPMVP.

Option B involves the long-term measurement of energy delivery directly by metering the plant's output or indirectly by determining savings based on an analysis of end-use meters. Unlike Option A, this option does not stipulate any aspect of system performance, and performance is measured over a prescribed time period.

Option C involves inferring savings by the statistical analysis of whole-facility energy consumption without end-use metering of the renewable energy system. Option C usually consists of analyzing information from gas and electric utility meters.

Option D involves predicting the long-term performance of a system or whole building by calibrating a computer model based on data from a short-term test.

These options are discussed in greater detail in the next section.

4 M&V Methods for Renewable Energy Systems

4.1 Introduction

This section discusses M&V of renewable energy systems within the framework established by the IPMVP. The reader is referred to Volume 1 of the IPMVP for the basic requirements of an M&V program, including M&V planning, statistical sample size, metering and instrumentation, cost vs. accuracy trade-offs, and adherence. The following is a more detailed discussion of the four M&V options listed in the IPMVP and in Section 3, above.

- Options A & B focus on measuring the performance of specific, easily isolated systems. Renewable energy system applications of these options could include photovoltaics, solar water heating, wind power, and biomass combustion.
- Option C measures the change in whole-facility energy use. This could be most suitable for such renewable energy systems as passive solar heating and daylighting, when those systems are integrated into the entire building and thus have an impact on overall performance.
- Option D allows the use of calibrated simulation(s) of the performance of a system or whole building to calculate savings created by systems integrated into the energy performance of the entire building. (See IPMVP, Volume III, Section A, "Concepts and Practices for Determining Energy Savings in New Construction," which treats the special issues of establishing a baseline and measuring performance in new buildings.) Option D also maximizes the value of limited data by providing an estimate of annual performance based on information resulting from a short-term test.

4.2 Option A: Partially Measured Retrofit Isolation

In this option, the capacity of a system to perform (for example, to deliver renewable energy) is measured, and operating conditions are stipulated. If the supplier and the customer can agree on values, energy and cost savings are calculated on the basis of an initial test of a renewable energy system's performance. Even then, periodic inspections and field measurements must be conducted to ensure that the systems are installed as specified, operating as expected, and satisfy any statutory or regulatory requirement that savings be verified periodically. This can be the least expensive M&V option; it is often suitable for small systems for which the cost savings are not sufficient to justify the expense of instrumentation and analysis. To avoid a conflict of interest, the project developer / ESCO and the customer may retain a third party to conduct inspections and take field measurements.

EXAMPLE OF OPTION A: SOLAR WATER HEATING TEST

A method developed at the National Renewable Energy Laboratory involves short-term monitoring of only one temperature channel (preheat tank temperature). Data are collected over several weeks and then reduced to a daily efficiency plot (by assuming clear-sky conditions) and compared with an expected line. This method is very useful for diagnostics to determine whether a system is working approximately as expected. It provides a reasonable ($\pm 30\%$) estimate of savings, provided there are several clear days during the monitoring period. The method uses a very inexpensive (less than \$100) temperature sensor and so is a low-cost metering approach. Mailing a data logger and videotape to the owner upon installation is a way to avoid the cost of a site visit (Burch, Xie, and Murley 1995).

4.3 Option B: Retrofit Isolation

In this option, the actual amount of energy delivery or the savings attributable to a renewable energy system are measured continuously. Option B differs from Option A in that no aspect of system performance is stipulated. Since renewable energy systems deliver rather than conserve energy, a distinguishing feature over efficiency measures is that performance (energy delivery) can often be measured directly with a meter.

Metering is a core part of an M&V program; however, the way in which metering fits into the M&V plan depends on specific performance claims. A program can be designed either to directly meter system output (with a thermal energy or electric meter) or to indirectly measure savings or production by subtracting post-installation energy use from baseline energy, after appropriate adjustments are made for changes in conditions.

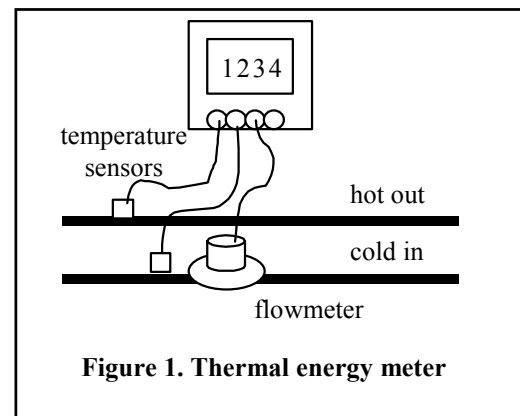


Figure 1. Thermal energy meter

The number of channels and the type of measurements distinguish metering strategies. A thermal energy meter consists of a flow meter, two temperature sensors, and integrating electronics, as illustrated in Figure 1. The energy delivery of a thermal renewable energy system (a solar water heater) is calculated automatically by multiplying the mass flow rate by the specific heat of the water and the temperature difference between cold water coming in and hot water going out. Most thermal energy meters also report flow and temperature data, which are useful for diagnostics.

It is possible to estimate energy savings indirectly by calculating the difference between the baseline load and the metered auxiliary (electric or gas) energy usage. The baseline could be established by the control

OPTION B, EXAMPLE 1: DIRECT MEASUREMENT, CENTRALIZED SOLAR HOT WATER

As an example of direct measurement in an Energy Savings Performance Contract, consider a 1,583-m² parabolic trough solar water heating system, valued at \$650,000, which was installed at the Phoenix Federal Correctional Institution in Arizona by Industrial Solar Technology (IST) Corporation.

Monthly payments from the prison to IST are equal to the monthly solar energy delivery (kWh), as measured by the thermal energy meter, multiplied by the average cost of utility power (\$0.074/kWh) and by a discount factor of 0.9 to guarantee that the prison will always realize 10% savings over utility power (see Figure 2). The system delivered 1,161,803 kWh and saved \$77,805 in utility costs in 1999. Payments to IST at 90% of the electric rate were \$70,025 in 1999. The term of the contract is 20 years.



Figure 2. A monthly bill is issued to a prison for actual energy delivered by a large solar water heating in Phoenix.

Two thermal energy meters are used in a series so that metering can continue if one meter is removed for calibration. Furthermore, each meter is calibrated to $\pm 5\%$, so if the two meters disagree by more than $\pm 7\%$ (RMS of 5% and 5%), then the meter with the higher reading is sent for recalibration.

group, before-and-after, on-and-off, or calculated reference method, as described in Section 2.

OPTION B, EXAMPLE 2: INDIRECT MEASUREMENT, RESIDENTIAL SOLAR HOT WATER

As an example of indirect end-use measurement, consider the monitoring of water-heating loads on a sample of 50 houses (25 with solar water heating and 25 without) at the Kia'i Kai Hale U.S. Coast Guard (USCG) Housing Area in Honolulu, Hawaii. A separate solar water heater 6 m² in area was installed on each housing unit (see Figure 3). Each electric water heater was fitted with a monitoring system to record power consumption every 15 minutes. Figure 4 summarizes data collected as the total water heating power for all 50 sample houses.



Figure 3. Solar water heating systems on USCG housing in Hawaii.

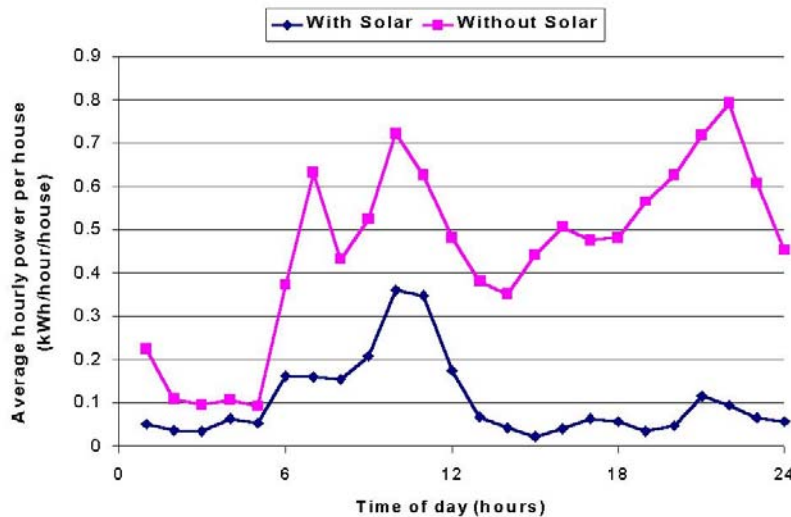


Figure 4. Daily electric water heating profile with and without solar water heating (control group baseline strategy) at USCG housing in Hawaii.

The 6 a.m. morning peak occurs on weekdays, while the later morning peak occurs on weekends. The entire housing area is connected to one utility meter. The facility water-heating peak is not simply the sum of each house's peak because of diversity in demand. The evening (5 to 9 p.m.) peak demand for all 25 houses without solar was 38 kW; it was only 12.2 kW for the 25 houses with solar water heating. Monitoring was for a 6-week period from June 11 to July 25, 2002, over which time the houses without solar systems used an average of 11.1 kWh/day for water heating, and those with solar systems used only 2.5 kWh/day, a savings of 8.6 kWh/day.

OPTION B, EXAMPLE 3: DIRECT METERING, WIND TURBINE VERIFICATION PROGRAM



Figure 5. Green Mountain Power 6.05 MW wind farm in Searsburg, Vermont.

The DOE-EPRI Wind Turbine Verification Program (TVP) provides field performance and operating data for advanced early-commercial wind turbines that have not been widely deployed. The program reports performance, reliability, maintainability, and cost. The program includes eight U.S. wind projects in Alaska, Iowa, Nebraska, Tennessee, Texas, and Vermont featuring a range of wind turbines supplied by European and U.S. manufacturers. Figure 6 shows an installation in Searsburg, Vermont, consisting of 11 Zond 550-kW turbines being monitored under the program. The project is instrumented to measure environmental conditions, electrical power, and power quality. Detailed reports include performance compared with the power curve of the turbine, power factor, and effect on grid voltage, as well as availability and reasons for forced and planned outages. During the 12-month period from July 1999 through June 2000, the Searsburg wind facility generated more than 13 million kWh of electricity. This represents a 24.6% average annual capacity factor based on 6.05 MW of installed capacity. The system availability was 86.5%, allowing for all scheduled and forced wind turbine outages. Availability for individual turbines ranged between 63.2% and 96.6%. The year of operation was marked by generator replacements for two turbines, destruction of a turbine blade by lightning, and an increased incidence of electrical and generator-related faults. However, compared with other TVP projects, the response time to faults remained relatively high. An important goal of this program is to transfer experience gained in the TVP projects to utilities, wind power developers, turbine vendors, government agencies, and other interested parties so the lessons learned can be incorporated into future projects. Operation reports describe negative as well as positive experiences. The information in these reports should help others avoid or reduce the impact of problems similar to those encountered in the program.

4.4 Option C: Whole-Building Analysis

This option involves the analysis of information available through utility bills or whole-facility metering. After the renewable energy system is installed, the utility bill (which constitutes the measurement) or

utility meter reading is subtracted from a baseline with adjustments for changes in use or in the operation of the facility, to determine energy savings. The baseline is determined using one of three techniques described in Section 2: the control group, before-and-after, or on-and-off technique.

Since driving forces such as weather and occupancy frequently change, Option C involves routine baseline adjustments. The post-retrofit energy consumption measurement is subtracted from baseline energy consumption to estimate savings.

The accuracy of this method is limited by the numerous variables affecting building energy use, and it may be most appropriate for applications in which renewable energy contributes a large part of the building load. The result of measuring all the independent variables needed to model energy usage (e.g., temperature, humidity, solar radiation, occupancy) generally would exceed the result of directly measuring the renewable energy system's output.

This would be a suitable M&V option when renewable energy systems are installed as part of a larger suite of energy efficiency measures. In such cases, load modeling and measurement of the driving functions would be conducted for measures such as daylighting and passive solar heating, which do not lend themselves to metering. If the baseline is established by a control group, participants may debate and determine by consensus the factors constituting sufficient similarity between the buildings. However, the intent here is to select a control group that is essentially identical to the sample (e.g., identical military housing units with the same use and in the same location).

4.5 Option D: Calibrated Simulation

In this method, a great amount of information can be provided by a short-term test. First, a model provides the form of the correlation between measured independent variables and measured system performance. The independent variables (i.e., load and ambient conditions such as solar radiation and temperature) are then measured and recorded simultaneously with system performance over a short time period. Next, coefficients of the model are adjusted to provide the best fit between modeled and measured performance. The calibrated model then becomes a valuable source of information. Deviations in model coefficients from their expected values provide information that can be used to diagnose system problems. Running the model with annual weather and load data provides an estimate of annual performance.

OPTION D, EXAMPLE 1: PHOTOVOLTAIC SYSTEM, THE PRESIDIO, SAN FRANCISCO

As an example of Option D applied to a photovoltaic system, consider a 1,250-W building-integrated photovoltaic (BIPV) system at the Thoreau Center for Sustainability at the Presidio, San Francisco, California (see Figure 6). The monitoring objectives were to verify initial system performance and to predict typical annual performance. Environmental conditions (ambient temperature, wind speed and direction, relative humidity, and insolation) were measured, and the coefficients of a computer model were adjusted to provide the best match with the measured system performance parameters (DC output and AC power output). The system was monitored between January and June 1998 in order to measure performance under the full range of sun angles that it will experience throughout the year.



Figure 6. Building-Integrated Photovoltaic System in the Presidio, San Francisco.

First, a TRNSYS (Klein 1994) shading model was calibrated to correlate the actual plane-of-array insolation with unshaded horizontal insolation, thus accounting for shading by surrounding objects, as well as the reflection off a large, white wall north of the BIPV system. The resulting model of solar radiation provides an R^2 of 0.985.

Second, the coefficients of a model of array DC power output as a function of environmental conditions were adjusted to provide the best fit between the array efficiency model and the measured data. The best fit was found using a model that takes into account the incidence-angle-modifier effects of the glass surface of the modules, the ambient temperature, and the total insolation falling on each of the two sloped surfaces.

OPTION D, EXAMPLE 1: PHOTOVOLTAICS (Continued)

Unlike that of the earlier solar thermal model example, the form of this equation is not determined by a thermodynamic model but rather by a general polynomial. The goodness-of-fit is shown graphically in Figure 7 with an R^2 of 0.70. Power is estimated with a standard deviation of ± 22.4 W. Third, the AC power output of the inverter was measured to perform a third least-squares regression to adjust an inverter efficiency model with R^2 of 0.932. Deviations of the inverter efficiency from expected values indicated a problem with the inverter's maximum-power point-tracking function. Again, the form of this equation is a general polynomial without physical derivation.

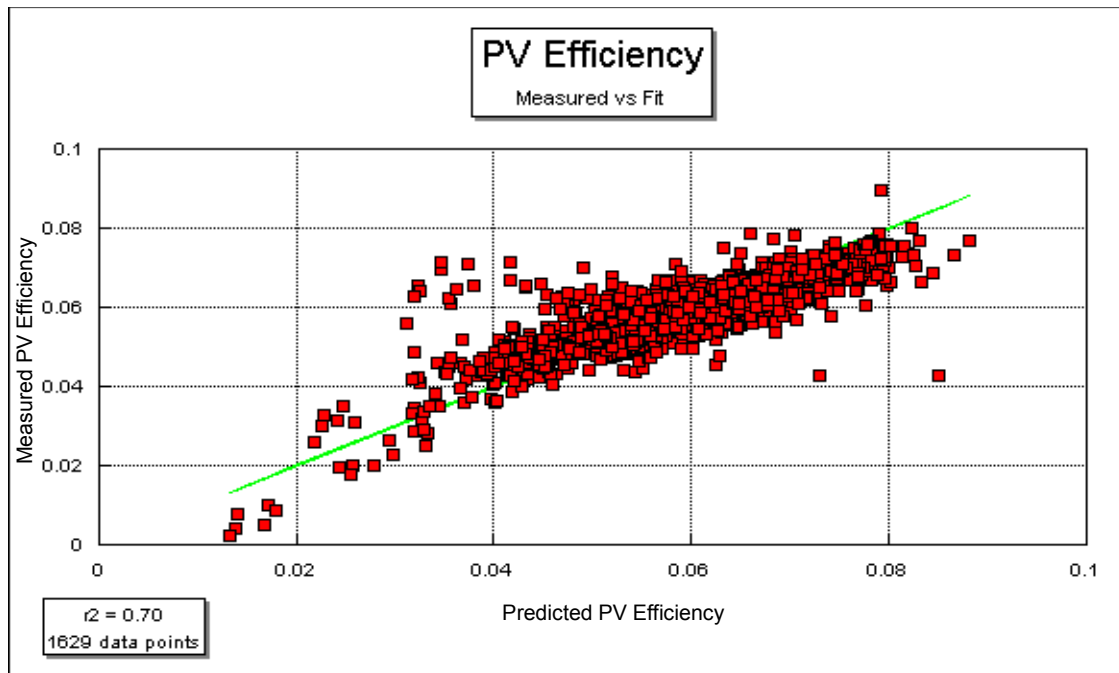


Figure 7. Predicted versus measured efficiency of a building-integrated photovoltaic system.

These three correlations constitute a calibrated composite model, which was fed typical meteorological year (TMY) weather data for San Francisco (NCDC, 1997) in order to estimate the annual energy delivery. This estimate took into account array orientation, shading, and reflection off the south wall, as well as the actual in situ performance characteristics of the array and inverter. The model predicts that under TMY conditions, the system would deliver 716 kWh AC per year without inverter repair and 2,291 kWh AC per year after the inverter is repaired. This technique can be used to predict the performance of a PV system in a typical year, especially in unusual shading conditions. As used in this case to diagnose the inverter problem, this technique can be employed in the initial commissioning process to make sure a system functions as expected.

OPTION D, EXAMPLE 2: SOLAR WATER HEATING

As an example of Option D, consider a method of evaluating solar water-heating system performance, which was developed at the National Renewable Energy Laboratory (Barker 1990; Barker, Burch, and Hancock 1990). The instrumentation is illustrated in Figure 8.

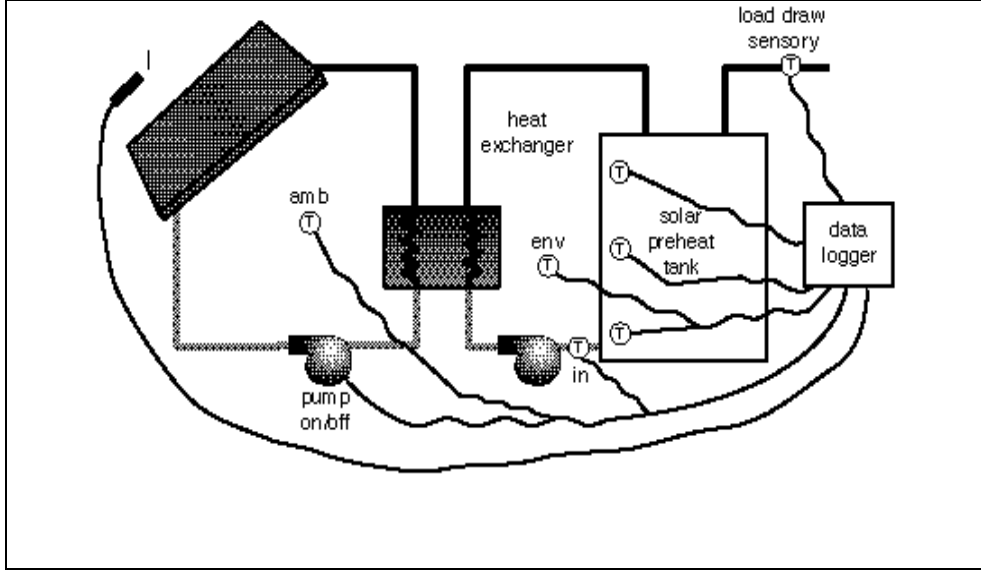


Figure 8. Short-term test apparatus for solar water heating.

The instrumentation measures the energy inputs and outputs over a time period sufficient to calibrate the performance model. The time period may be as short as one day, but it must encompass a sufficiently wide range of conditions (sunny/cloudy, warm/cold). The first law of thermodynamics sets energy collected equal to energy stored plus energy lost from the storage tank. Efficiency as measured in the short-term test,

$$\text{Efficiency} = [dE/dt + U_s (T_s - T_{env})] / [I \cdot A_c] , \quad (\text{Eq. 1})$$

is correlated by linear regression with a linear model:

$$\text{Efficiency} = \tau\alpha - U_c (T_s - T_{amb}) / I , \quad (\text{Eq. 2})$$

where:

- I = incident solar radiation (W/m^2)
- A_c = collector area (m^2)
- T_s = average storage water temperature ($^{\circ}\text{C}$), representing collector inlet temperature
- T_{amb} = ambient temperature ($^{\circ}\text{C}$)
- T_{env} = temperature of storage tank location ($^{\circ}\text{C}$)
- dE/dt = time rate of change of energy in storage tank (J/s), as measured by the average of three tank temperatures
- U_s = heat loss coefficient of storage tank estimated by cool-down rate ($\text{W/m}^2\text{C}$).

The term $\tau\alpha$ is an empirical constant representing all the effects of the transmissivity of the cover glass and the absorptivity of the absorber plate. U_c is a term representing all the effects of the thermal loss coefficient of the collector and piping per unit area ($\text{W/m}^2\text{C}$). These two coefficients in the model are adjusted to minimize the difference between measured and simulated performance. The calibrated model is then supplied with an hourly load profile and with ambient temperature and incident solar radiation for all 8,760 hours of the year from typical meteorological year data (NCDC 1997) to predict annual performance. This simple model is isothermal, with the collector and storage all at an average T_s .

OPTION D, EXAMPLE 2: SOLAR WATER HEATING (Continued)

This method of calibrating a computer model was used to test the performance of 13 systems in Colorado (Walker and Roper 1992). Figure 9 shows the results of a one-day test on a system with an 8.9-m² collector area.

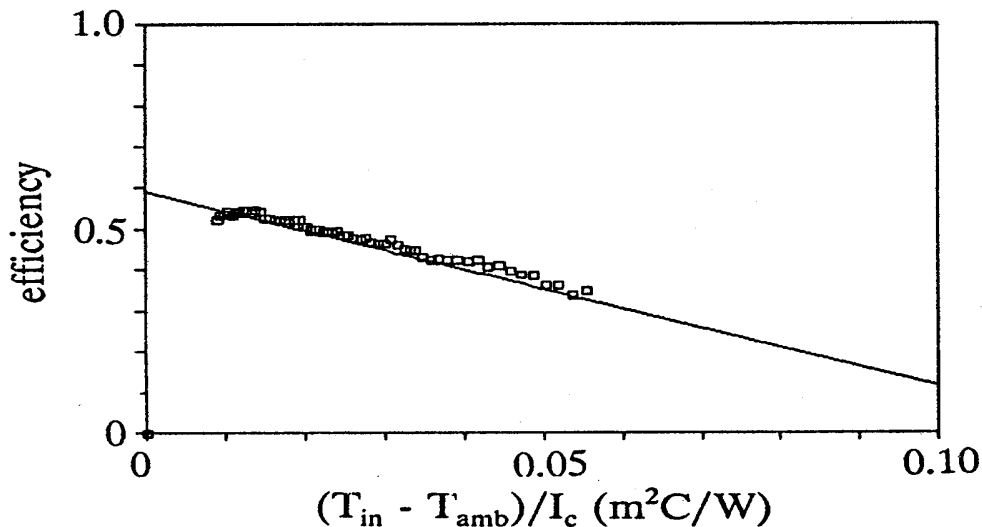


Figure 9. Results from one-day test of a solar water heating system.

The square symbols signify measured data for every 5-minute interval, and the solid line is the best-fit linear regression (the renormalized model). This test was conducted on a clear day, and very good agreement is achieved between the model and the measured performance. The test starts the day with a cool tank, which heats up over the course of the day, providing a wide range of the parameter $(T_s - T_{amb})/I$. The model inputs that were derived consist of $\tau\alpha = 0.59$ and $U_c = 4.7$ W/m² °C. The simulation used Colorado Springs weather data to predict a typical annual energy delivery of 5,388 kWh/year.

5 Quality and Cost of M&V for Renewable Energy

M&V programs inherently provide the quality assurance needed in renewable energy projects. M&V costs, however, can vary greatly according to the requirements of a particular project.

The total costs of an M&V program includes the cost of purchasing, installing, and maintaining the instrumentation (including periodic calibration); the cost of the labor involved in designing the program; and the cost of periodically collecting, reducing, and presenting the results of the program. Overly detailed or poorly designed M&V programs can be very expensive, so the amount of money to be spent should be determined by the value of the benefits that result from the M&V program, as mentioned in Section 1.

The value of these benefits is determined through negotiations between the customer and the project developer for each project. The objective is for all parties to work together to minimize the total cost of the M&V program as well as the cost of uncertainty as to savings. The cost of this uncertainty is most often realized in a higher interest rate.

In order to lower project costs, the customer may assume some performance risk by agreeing to periodic and limited (rather than continuous) measurements or by increasing the allowable error in the measurements. Other requirements of a particular M&V program might include verification for emissions credits or other certifications of regulating bodies, as noted in Section 1. Total costs will also include the cost of measuring and verifying these kinds of requirements.

6 Other Resources

The objectives and activities of several organizations are closely related to the subject matter of this chapter of the IPMVP. These organizations are listed in alphabetical order below, along with a short description of each one. More information can be found on the World Wide Web; Web addresses are included in each description.

6.1 ACRE

The Australian Cooperative Research Center for Renewable Energy (ACRE) in Perth, Australia, seeks to create an internationally competitive renewable energy industry. ACRE brings together excellent research capabilities and market knowledge into a world-class center for the innovation and commercialization of renewable energy systems. One of the principal objectives of the center includes presenting a strategic policy framework to government and energy agencies that can help provide the basis of a viable renewable energy industry in Australia. <<http://fizzy.murdoch.edu.au/acre/>>

6.2 ASTM

The mission of ASTM International—formerly known as the American Society for Testing and Materials (ASTM)—headquartered in West Conshohocken, Pennsylvania, is to provide “the value, strength, and respect of marketplace consensus.” ASTM’s main functions are (1) to develop and provide voluntary consensus standards, related technical information, and public health and safety services having internationally recognized quality and applicability that promote overall quality of life; (2) to contribute to the reliability of materials, products, systems, and services; and (3) to facilitate regional, national, and international commerce. ASTM’s primary strategic objective is to provide the optimum environment and support for technical committees to develop needed standards and related information. <<http://www.astm.org/>>

6.3 CEN

The mission of the European Committee for Standardization (CEN), based in Brussels, is to promote voluntary technical harmonization in Europe in conjunction with worldwide bodies and European partners and to develop procedures for mutual recognition and conformity assessment to standards. Harmonization diminishes trade barriers, promotes safety, allows interoperability of products, systems, and services, and furthers technical understanding. In Europe, CEN works in partnership with the European Committee for Electrotechnical Standardization (www.cenelec.be) and the European Telecommunications Standards Institute (www.etsi.fr). CEN’s Strategic Advisory Body on Environment promotes developing measurement methods for environmental quality and pollution emissions; standardizing tools and instruments of environmental policy; and incorporating environmental aspects in

product standards. CEN and ISO have parallel procedures for public inquiry and formal votes on international standards. <<http://www.cenorm.be/>>

6.4 ESAA

The Electricity Supply Association of Australia Limited (ESAA), based in Sydney, is the prime national center for issues management, advocacy, and cooperative action for Australian electricity supply businesses. ESAA's members consist of both public and private businesses involved in generating, transmitting, distributing, and retailing electricity in Australia together with associate, affiliate, and individual memberships from Australia and overseas. <<http://www.esaa.com.au/>>

6.5 IEA

The International Energy Agency (IEA) is an autonomous body, established in 1974 within the framework of the Organization for Economic Cooperation and Development, to implement an international energy program. More than 60 programs currently operate through the IEA; each reflects the need for efficient coordination among international organizations and bodies. Programs are carried out under the framework of an implementing agreement signed by contracting parties, which include government agencies and government-designated entities of the countries involved. Implementing agreements provide a framework for collaborative research projects. Benefits include pooled resources and shared costs, harmonization of standards, and hedging of technical risks. <<http://www.iea.org>>

The mission of the IEA Photovoltaic Power Systems (PVPS) Program, based in the United Kingdom, is to enhance the international collaboration efforts—in particular, research, development, and deployment—by which photovoltaic solar energy will become a significant energy option in the near future. Objectives related to reliable PV power system applications for the target groups (utilities, energy service providers, and other public and private users) include increasing the awareness of PV's potential and value and fostering market deployment by removing the nontechnical barriers. <<http://www.caddet-re.org/html/pvpsp.htm>>

IEA's SolarPACES Program is looking ahead strategically by cooperating intensively on research and technology development in solar thermal power and solar chemistry. This program is also initiating activities to support project development to tackle nontechnical barriers and to build awareness of the relevance of solar thermal power applications to the current problems of energy and the environment. <<http://www.solarpaces.org>>

6.6 IEC

The International Electrotechnical Commission (IEC), based in Geneva, is the international standards and conformity assessment body for all fields of electrotechnology. The IEC's mission is to promote, through its members, international cooperation on all questions of electrotechnical standardization and related matters, such as the assessment of conformity to standards in the fields of electricity, electronics, and related technologies. The IEC charter embraces all electrotechnologies, including electronics, magnetics and electromagnetics, electroacoustics, telecommunication, and energy production and distribution, as well as associated general disciplines such as terminology and symbols, measurement and performance, dependability, design and development, safety, and the environment. <<http://www.iec.ch/>>

6.7 IEEE

The vision of the Institute of Electrical and Electronics Engineers, Inc. (IEEE), headquartered in New York City, is to advance global prosperity by fostering technical innovation, enabling members' careers, and promoting community worldwide. IEEE promotes the engineering process of creating, developing, integrating, sharing, and applying knowledge about electrical, electronic, and information technologies and sciences for the benefit of humanity and the engineering profession. An IEEE effort (SCC21 Committee and Work on Standard P1547) is under way to establish utility interconnection standards important to broad implementation of grid-connected renewable energy distributed generation technologies. <<http://www.ieee.org/>>

6.8 ISO

The International Organization for Standardization (ISO), based in Switzerland, is a nongovernmental, worldwide federation of national standards bodies from 130 countries. The mission of ISO is to promote the development of world standardization and related activities with a view to facilitating the exchange of goods and services and to developing cooperation in the spheres of intellectual, scientific, technological, and economic activity. ISO's work results in international agreements that are published as International Standards. <<http://www.iso.ch/>>

6.9 JRC

The mission of the European Commission Joint Research Center (JRC), based in Brussels, is to provide customer-driven scientific and technical support for the conception, development, implementation, and monitoring of European Union (EU) policies. As a service of the European Commission, the JRC serves as a reference center of science and technology for the EU. Close to the policy-making process, it serves the common interest of the member states, while being independent of private or national special interests. <<http://www.jrc.cec.eu.int/jrc/index.asp>>

Within the JRC is the Environmental Institute and its Renewable Energies Unit, of which the European Solar Test Installation (ESTI) is one of the work fields. The mission of ESTI is in line with the mission of the JRC: to provide the scientific and technical base for the harmonization of standards within the single market of the European Union. One of the services for testing PV devices and systems includes support to standards organizations. ESTI is actively involved in quality assurance accreditation, both of its own expertise (to EN45001) and in helping industry attain accreditation according to internationally accepted standards (CEC, ISO, and IEC). <<http://iamest.jrc.it/esti/esti.htm>>

6.10 PV GAP

The Global Approval Program for Photovoltaics (PV GAP) is a global, PV industry-driven organization that strives to promote and maintain a set of quality standards and certification procedures for the performance of PV products and systems to ensure high quality, reliability, and durability. Registered in Switzerland, PV GAP is a not-for-profit organization that focuses on certifying the quality of PV systems. PV GAP also concentrates on the enforcement of international standards that promote the integration of quality. This organization works to introduce testing standards into the financing stream. It also seeks to establish international reciprocity of recognition of standards and testing laboratories. PV GAP has developed a professional collaborative relationship with the IEC, based on that organization's long-standing international reputation for quality and its common technical interests with the goals of PV GAP. The International Electrotechnical Commission Quality Assessment System for Electronic Components carries out the certification program for PV GAP. <<http://www.pvgap.org/>>

6.11 SRCC

The Solar Rating and Certification Corporation (SRCC) in Cocoa, Florida, is an independent, nonprofit organization that measures, rates, and certifies solar water heating system performance. SRCC's "Solar Energy Factor" ratings allow the comparison of savings provided by many different types of solar water-heating systems and conventional water heaters. SRCC certification has become a code requirement in 12 states across the United States and is being considered as a requirement in other states.

<<http://www.theenergyguy.com/SRCC.html>>

6.12 TUV

The primary mission of TÜV Rheinland (TUV) is to protect the health and safety of consumers and the environment by helping industry produce safer and better products. Industry customers work with TUV to achieve product differentiation and a competitive advantage through better methods and technology in research, design, development, manufacturing, and service. Customers comply with applicable regulations or guidelines and, in many cases, go well beyond minimally acceptable standards to achieve "best in class" status. <<http://www.tuv.com/>>

On its Web site, TUV mentions that the "EU has created an Internet site that provides access to the texts of CEN marking directives, standards officially recognized under those directives, and standards under development with a view to recognition under the same directives." These texts can be viewed and searched at <http://www.newapproach.org/>.

6.13 UNSW

The Photovoltaics Special Research Center at the University of New South Wales (UNSW) in Sydney, Australia, is a world leader in high-efficiency silicon solar cell research and is involved in major commercialization projects for clean, low-cost, large-scale power generation.

<<http://www.pv.unsw.edu.au/>>

6.14 UPVG

The Utility PhotoVoltaic Group (UPVG) has 150 member organizations. It is led by 100 electric service providers from eight countries working together to advance the use of solar photovoltaic power. UPVG is a nonprofit association based in Washington, DC, that receives funding from the U.S. Department of Energy to manage TEAM-UP (Technology Experience to Accelerate Markets in Utility Photovoltaics), a program to put photovoltaics to work in applications that have strong potential for eventual mainstream use. TEAM-UP is helping to create an expanded market for solar electricity. TEAM-UP awards cost-sharing dollars on a competitive basis. <<http://www.ttcorp.com/upvg/>>

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